A STUDY ON EFFECT OF VIBRATION AND TEMPERATURE ON HUMAN PERFORMANCE

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JULY, 1981

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A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

By

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to the

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

JULY, 1981

CERTIFICATE

This is to certify that this thesis entitled, "A Study on Effect of Vibration and Temperature on Human Performance," submitted in partial fulfilment of the requirements for the Degree of Master of Technology by Mr. Kashi Naresh Singh, is a record of work carried out under my supervision and has not been submitted elsewhere for a degree.

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July, 1981

ACKNOWLEDGEMENTS

I am extremely grateful to Prof. J.L. Batra for suggesting me the problem and extending proper guidance and supervision right from the conception to conclusion of my work. Inspite of his quite busy schedule he did not mind sitting with me till late in the night while the experimental set-up was being built. His affectionate behaviour all through out had been a constant source of encouragement for me.

I am thankful to my employer, the Patna University and the Principal Coordinator, Quality Improvement Programme for providing me an opportunity to do my Master's without being put to financial hardships.

I must thank the faculty members of IME and ME Departments for their help and encouragement.

I am really thankful to my friends who kindly offered themselves for being used as subjects in my experiments. Their unconditional cooperation even under odd conditions was solely responsible for the completion of my work.

Some of my friends, namely, Mr. Wasim Abbas, Mr. B.M. Sinha and Mr. Prabhas Kumar proved to be of real help to me in my work. My thanks are due to them.

The cooperation extended to me by the staff of IME and ME labs. is highly appreciated.

I appreciate the help rendered to me by Mr. Santokh Singh in the analysis of experimental data.

Mr. D.K. Sarkar completed the photographs work, while Mr. J.K. Misra, Mr. D.K. Misra and Mr. Buddhi Ram Kandiyal and Mr. Lalta Prasad took care of typing, tracing and cyclostyling work. Without their help the dissertation could not have taken its present form.

I must thank my wife and children who patiently bore with me the neglect towards the family while I was busy with my project.

Lastly, I thank all my friends and well wishers who, tangibly or intangibly, contributed towards the accomplishment of my work.

Kashi Naresh Singh

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ABSTRACT

Engineers and researchers concerned with the prediction of human performance in "man-environment systems" have been studying the effects of various factors on decision making and discrete motor responses involved in these systems. This work presents an experimental study which investigates the effects of vibration, temperature and exposure time on human performance in a simple steering task representative of those encountered in ordinary road vehicles. Performance measures of interest are reaction time and task performance time. Also the effects of these factors on heart rates of subjects are investigated.

A completely randomised 3x3x3x12 factorial design is used for the purpose. The different levels of vibration frequency, amplitude and temperature are 5 Hz, 10 Hz, 15 Hz, 0.09 in., 0.12 in., 0.15 in. Double Amplitudes and 70°F, 85°F, 100°F respectively. The duration of vibration exposure is kept one hour in each case. Six subjects are used for the purpose of study.

Vibration frequency and exposure time are found to significantly affect the human performance time for the specific task under consideration. Amplitude and temperature are not found to be significant factors within the limits of their ranges. However, performance time is found to be

increasing with amplitude and temperature levels. Reaction time and heart rate are found to be quite invariant to these factors within the limits of environmental conditions under study. A model to predict the performance time for various levels of vibration frequency and exposure time is developed. The findings reported in this dissertation may be of considerable utility to the engineers responsible for the design of roads and automobiles.

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

1.1 INTRODUCTION:

In olden days human beings lived in an essentially 'natural' environment. Their existence virtually depended on what they could do directly with their hands. With the passage of time several new facilities and environments were developed as a result of which man's life became more and more tolerable. In the world of today most of the things that we use are man made and hence it can be said that human beings of our present world live in very much of a man-made environment . By environment we may not necessarily mean only the ambient environment rather the whole of man-made objects, facilities that we use in the various aspects of our lives and also the physical environments in which we live.

It is argued that the present human being is the result of evolutionary processes over millions of years and hence has developed substantial adaptability to the environments he lives in. However, there is limit to one's range of adaptability to environmental variables. With the rapid development in the field of science and technology people have been busy in developing new environments which seek more and more

'compatibility' with human beings in terms of human comforts, safety and efficiency. The presumption behind all such developments has been that a particular design of such environment may enhance or degrade the level of human functional effectiveness and welfare. An environment - be it physical or otherwise, all the time produces stimuli. These are received by man's receptor organs, e.g. eyes, ear, nose, skin etc., processed and decision taken thereon by the brain and responded accordingly by the receiver. The environment also, in turn, reacts to these responses and this information is fed back into the human brain. Whenever, we talk in terms of output, we take into consideration the system as a whole. This system is referred to as man-environment system and the objective of such systems is to have an optimal design so as to enhance human functional effectiveness and maintain in the process, certain desirable human values such as health , safety and satisfaction.

The basic criteria in the design of a man-environment system is that the environment must be compatible with the human component. It involves several important steps, e.g., outlining the overall system performance criteria and objectives, identifying the functions required to be performed to meet the objectives and finally evaluating the overall system performance. The last amongst these i.e., the evaluation of

system performance is the most important step as the acceptance or otherwise of a particular system depends upon whether its performance is satisfactory or not. There are different types of human criterion for the evaluation of system performance. They may be human performance measures, namely, simple reaction time, performance time for a given task etc; physiological indices such as heart rate, oxygen consumption; subjective responses indicating whether a particular environment is tolerable, annoying, extremely annoying, alarming and the like.

As seen above, man can work efficiently and safely within rather limited environmental conditions. Exposure to extreme environments may result in serious physiological and psychological problems. Naturally, therefore, the problem remains to determine the tolerance limits and safety ranges under different environmental conditions. Since it is simply not possible to cover all aspects of the environment we may study only those that are of most general concern.

Vibration which results largely due to man's tremendously increased mobility in recent years is a parameter one should be concerned about. It is a common condition in all types of road and space vehicles and also around heavy industrial machinery. Vibration is said to be very severe in high-speed flight at low altitudes where air turbulence causes a

very rough or jolting ride. With the interest shifting towards manned space flight, it is being realised that rocket launches could produce vibration environments severe enough to affect astronaut's performance. Low frequency and high amplitude vibrations are encountered in ships resulting in motion sickness. Similarly temperature is another factor of general concern. High temperatures are encountered in several industrial situation viz. near coke ovens, steel melting shops, textile mills, electric lamp industries and a host of other places. Exposures to such environments may result in physical injury and impairment of human work efficiency. The other physical environmental variables which may be of general interest are noise, illumination etc.

1.2 REVIEW OF LITERATURE:

Although the history of research into the effects of ambient environmental variables on human beings covers about half a century, it received significant attention only two decades ago. A wealth of literature (1-25) has been devoted to studying the psychophysical effects of variables like vibration, temperature, noise etc. on human beings.

1.2.1 Vibration:

Vibration research has covered different types of human performance capabilities. Some investigators have worked on subjective responses whereas others have studied the manual

tracking capabilities. Effect of vibration on visual acuity and tasks involving reaction times, monitoring and pattern recognition has also been of considerable interest to several research workers.

Magid, et.al. (15) have made rather extensive determinations of subjective tolerances for exposures to vibration frequencies between 1 and 20 Hz. in the vertical direction. They have shown that minimum tolerance occurs at 5 Hz. Parks (18) rated the different vibration levels in z-direction as (1) definitely perceptible, (2) mildly annoying, (3) extremely annoying and (4) alarming. His results are in conformity with those of Magid, et.al. Shoenberger and Harris (22) made quantitative characterization of subjective response to vibration. Using the methods of magnitude estimation and intensity matching, they constructed curves of equal subjective vibration intensity over the frequency range of 3.5 to 20 Hz. They reported maximum sensitivity around 5 Hz.

The most frequent performance measure used in vibration research has been some form of tracking, usually compensatory tracking in two dimensions. Boeing [2] studied the effect of vibration on vertical tracking performance and reported significant decrement in the performance at 15 c/s and at an amplitude level sufficient to produce a peak 'g ' of 1.5. However, Mozell and White [16] found no significant decrement for

either frequency or amplitude on vertical tracking performance. They carried out their studies in the frequency range of 8 - 23 c/s and double amplitudes of 0.05 in., 0.1 in. and .16 in. Simons and Schmitz [23] have reported some decrements in horizontal tracking performance under vibration. Frazer et. al. [8] found that tracking performance was significantly affected by vibration (at 2, 4, 7 and 12 c/s, 1/16 in., 1/8 in., 3/16 in. and 1/4 in. DA) in the vertical and horizontal planes. Catterson [4] reported that two-dimensional tracking performances changed significantly as a function of frequency, amplitude and both. However, decrements were observed only at an amplitude level of .16 in. DA. Buckhout [3] reported significant decrement in vertical tracking performance under vertical sinusoidal vibration at 5, 7 and 11 c/s and amplitudes corresponding to 25, 30, 35% of human tolerance limits. Harris and Shoenberger [9] reported that decrement in tracking performance was proportional to amplitude and was maximum at 5 c/s. Shoenberger [21] studied the effects of direction and frequency of vibration on human tracking performance and reported greatest decrement at 1 and 3 c/s in X and Y axes. Stave [24] studied the influence of vibration of frequencies from 6 to 12 Hz and amplitudes corresponding to the acceleration from ± .1 to ± .3 g on pilot performance. It was reported that pilot's performance tended to improve with increased stress. It was then hypothesized that the trend was due to the motivation of the pilots.

The effects of vibration on reaction time and other perceptual judgements also caught considerable attention of the researchers. Coermann [5] was perhaps the first to have studied the effects of vibration on choice reaction time. Using high frequency vibration conditions (30 - 1000 Hz) he found no consistent effects on reaction time. Similarly Schmitz [20], in a simple foot reaction test, found no effect. Hornick [11] reported decrement in choice reaction time after the vibration exposure but not during it. Holland [10] similarly, found no significant decrement in choice reaction time as a result of 6 - hr. exposure x to random vibration in z-direction. Likewise, Hornick and Lefritz [12], Duden and Clemens [7] also reported no decrement in reaction time. A study by Shoenberger [19] using all the three axes and frequencies from 1 through 11 Hz. found some decrements in choice xreaction time. Except for the Y-axis condition, however, the decrements were slight and of marginal statistical significance.

In general, research on performance under vibration led to conflicting findings and very little in the way of generalizable empirical data and hence a definite need exists for empirical data on the effects of vibration on human performance.

1.2.2 Temperature:

Cause and effect type of studies on the relationship of thermal stress and human performance indicate that the way in

which this environmental variable affect such performances is rather complicated. A few relevant studies are referred to here.

Mackworth [17] studied the effects of effective temperature (ET) on the amount of work done. He reported considerable decrement in performance of all types of subjects beyond an ET of 79°F (or Dry bulb temp. 85°F, wet bulb 75°F). Wyon [26] studied the effect of two levels of temperatures (20°C and 24°C) on the performance of typists and reported that they worked more in an environment of 20°C than at 24°C.

Azer et.al. [1] made a study of tracking performance of different groups of subjects under various combination of temperature and humidity, they reported significant degradation in performance at an ET of 89.8°F (Temp. 95°F RH 75%). Nunneley [19], in a study on tracking task performance, found that the simplest task showed a small but statistically significant improvement in time on target with heat, while two more difficult tasks showed no change.

Colquhoun and Goldman [6] reported that the core temperature was one of the factors that was responsible for performance decrement in vigilance tasks.

Wing [25] developed a generalised pattern of temperature-duration function related to mental performance. He identified, from the several studies, the lowest temperature

at which a statistically significant performance decrement occured. He suggested that the thresholds for at least some mental tasks might be between the lower curve and the tolerable physiological-limit curve in the case of fully acclimatized or highly practiced individuals.

1.3 THE PRESENT WORK:

In the present work an attempt has been made to study the effects of vibration and temperature on human reaction and performance times while performing a prespecified task. Six subjects are subjected to vertical vibration of frequencies 5, 10 and 15 c/s and amplitudes .09 in., .12 in., and .15 in. DA at temperatures of 70°, 85° and 100°F. The study is carried out in a simulated environmental chamber where these parameters are manipulated artificially. The different time measurements are taken with the help of two digital stop timers. The significant influencing parameters and their levels are identified by multi-factor ANOVA and the inter-relationship is established through multiple regression technique.

The experimental details of various set-ups used and the task design are discussed in Chapter II of the dissertation.

The methodology used in collecting and analyzing the data is given in Chapter III. The discussion on results are presented in Chapter IV. The conclusions and suggestions for further work are outlined in Chapter V.

CHAPTER II

EXPERIMENTAL COMPLEX

In the previous chapter the problem of studying the effects of environmental parameters on human performance was introduced. Also the importance of such studies was briefly outlined. The present chapter deals with the description of the whole experimental complex consisting of the environmental chamber, instrumentation set-up and the design of the task specified for the purpose.

2.1 ENVIRONMENTAL CHAMBER:

An environmental chamber of size 10' x 10' x 10' was designed and got fabricated for the purpose of controlling the temperature. The chamber enclosed the shake table installed on a 5' x 3' x 2' concrete block. It was constructed using wooden panels of suitable size. Thermocole sheets of size 1 m x 1/2 m x 50 mm were fitted to these wooden panels to ensure proper insulation and the panels were covered from both sides by plywood sheets of 6 mm thickness. Thus the final thickness of the walls and the roof of the chamber was 2.5 in.

An air-conditioner of capacity 1.5 tonnes was fitted in the chamber to bring down the temperature inside the chamber

to desired levels. Also a strip heater was fitted in front of the blower of the AC unit to raise the temperature above atmospheric temperature. A thermostat of range 30°C - 110°C was put in the circuit to control the temperature. The other instruments used inside the chamber are as follows:

i) Two digital stop clocks to measure the reaction and performance times.

ii) 4-Channel Encardiorite recorder.

iii) Heart Rate meter.

iv) Dry Bulb and wet bulb thermometer.

v) A small circular mirror fitted on a gyroscope.

vi) A light source

Figs. (1 to 5) show the photographs of the different portions of the environmental chamber and the instruments kept therein.

2.2 INSTRUMENTATION SET-UP:

Shake Table: Vibration stimuli were produced by an electro-magnetically driven All American Fatigue Testing Machine, Model 150-VP-T (Vertical). It consisted of a 21" x 18" platform mounted on a piston type mechanism actuated by a connecting rod and eccentric shaft running in an oil bath. This piston type of mechanism provided true perpendicular motion with a minimum of extraneous vibration. A 2 H.P. 220 volts, 60 cycle AC, 3 phase motor was fitted to drive the machine. Frequencies that could be changed manually or automatically were indicated

on the dial of an electric tachometer. The range of frequency was 0 to 100 Hz. Displacements (double amplitudes or DA) could be easily adjusted from 0 to 0.15 inch. The maximum work load that could be handled by the machine was 150 lbs. Fig. (6) shows the photograph of the machine.

Seat Design: The seat design considerably influences the performance of the subjects who are supposed to use the same while performing some work activities. The principles of seat design has been dealt with at length in [29]. Macfarland and Stoudt [14] have made the following recommendations for the design of driver seats and in the present work an attempt has been made to follow the same.

Seat height - 14" (35.5 cm) with an optimum range of 10-14
Seat depth - 18" (46 cm)
Seat width - 18" (46 cm)
Back-rest height - 18 - 21 inches
Back-rest width - 20" (50 cms) minimum
Seat Surface angle- 7° from horizontal
Back-rest angle - 112° from horizontal

In the present work a seat, without cushion and 18" x 18" in dimensions, was rigidly fixed on the shake table. The seat surface was slightly concave and its inclination with the horizontal was about 7°. The height and width of the back-rest was 18" each and its inclination with the seat

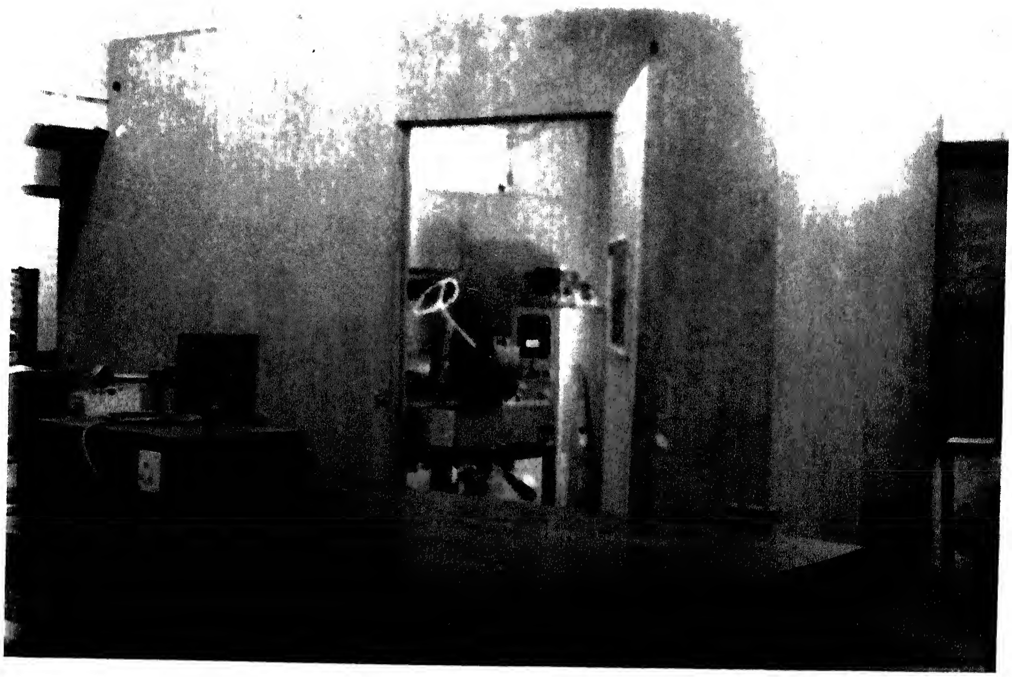


Fig. 1 : Photograph showing the environmental chamber

Fig. 2: Photograph showing the seat and the steering mechanism mounted on the shake table.

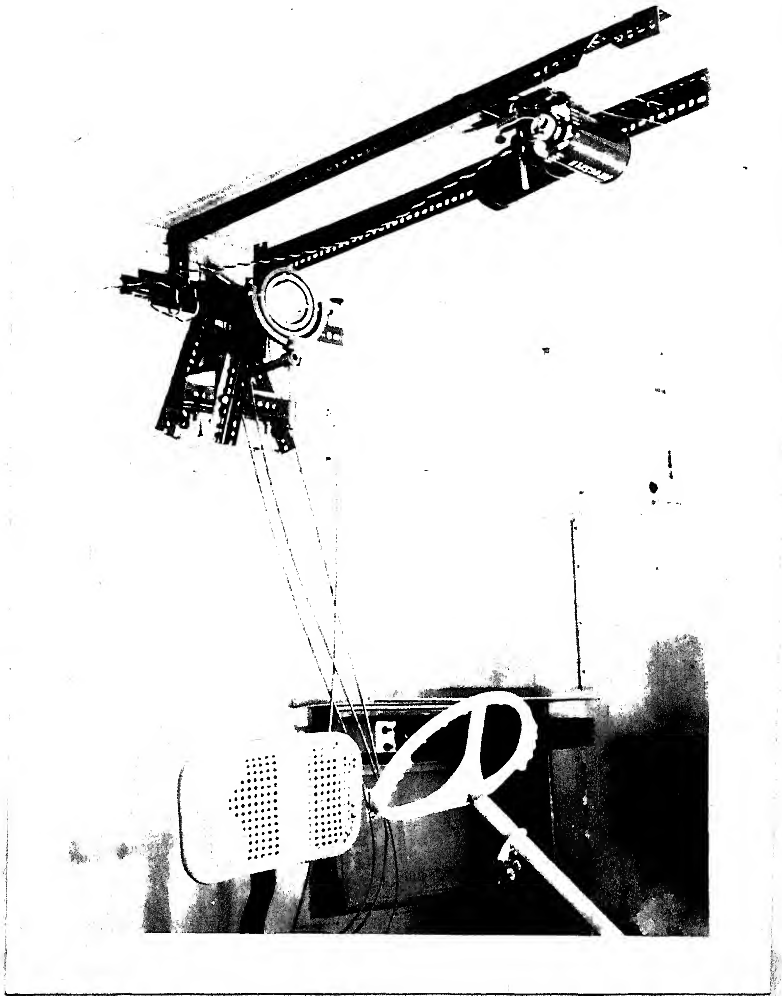


Fig. 3: Photograph showing the light source
and the mirror fitted onto a gyroscope

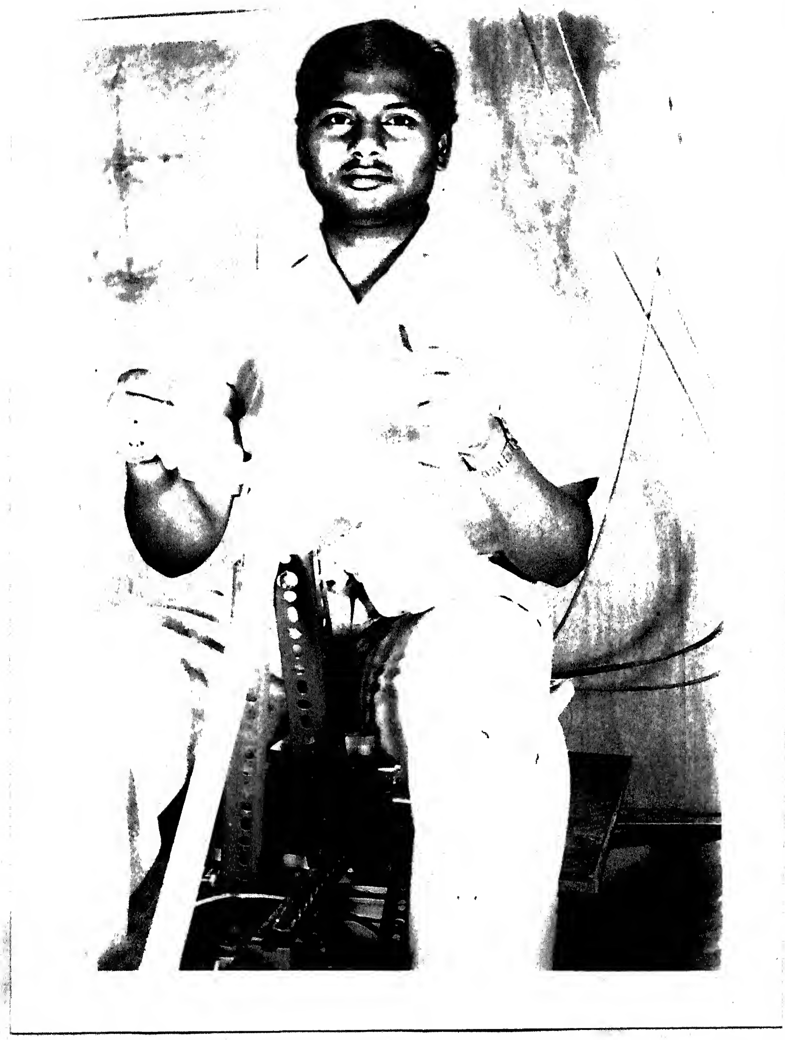


Fig. 4: Photograph showing a subject performing the task

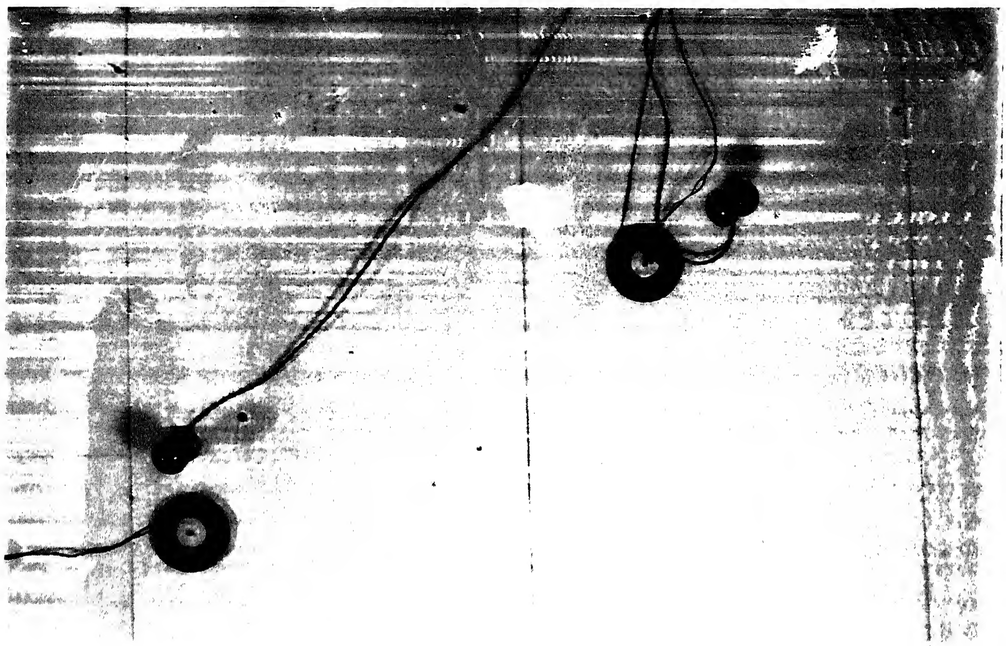


Fig. 5: Photograph showing the targets alongwith the two visual signals

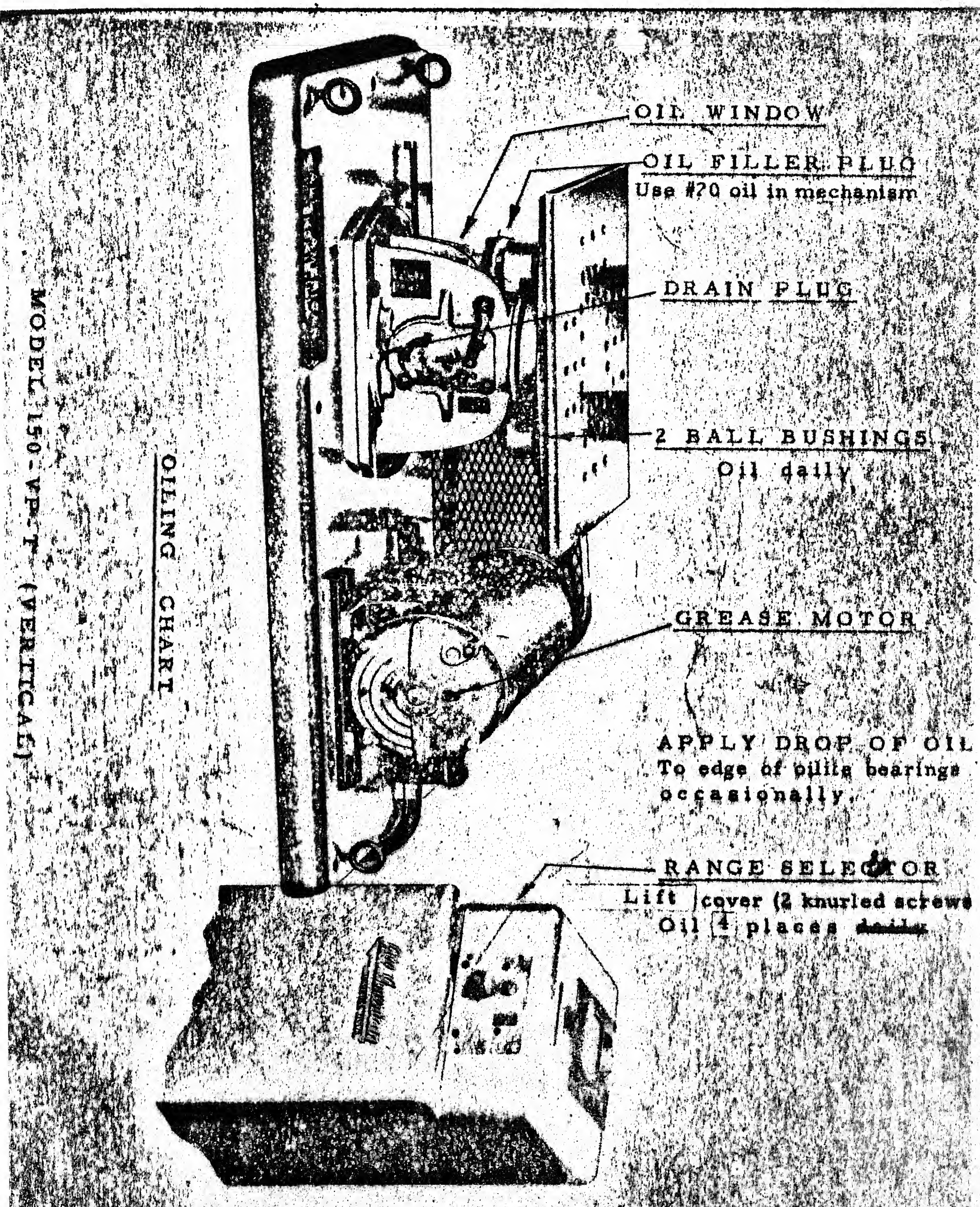


Fig. 6 : The Vibration Testing Machine (Shake Table)

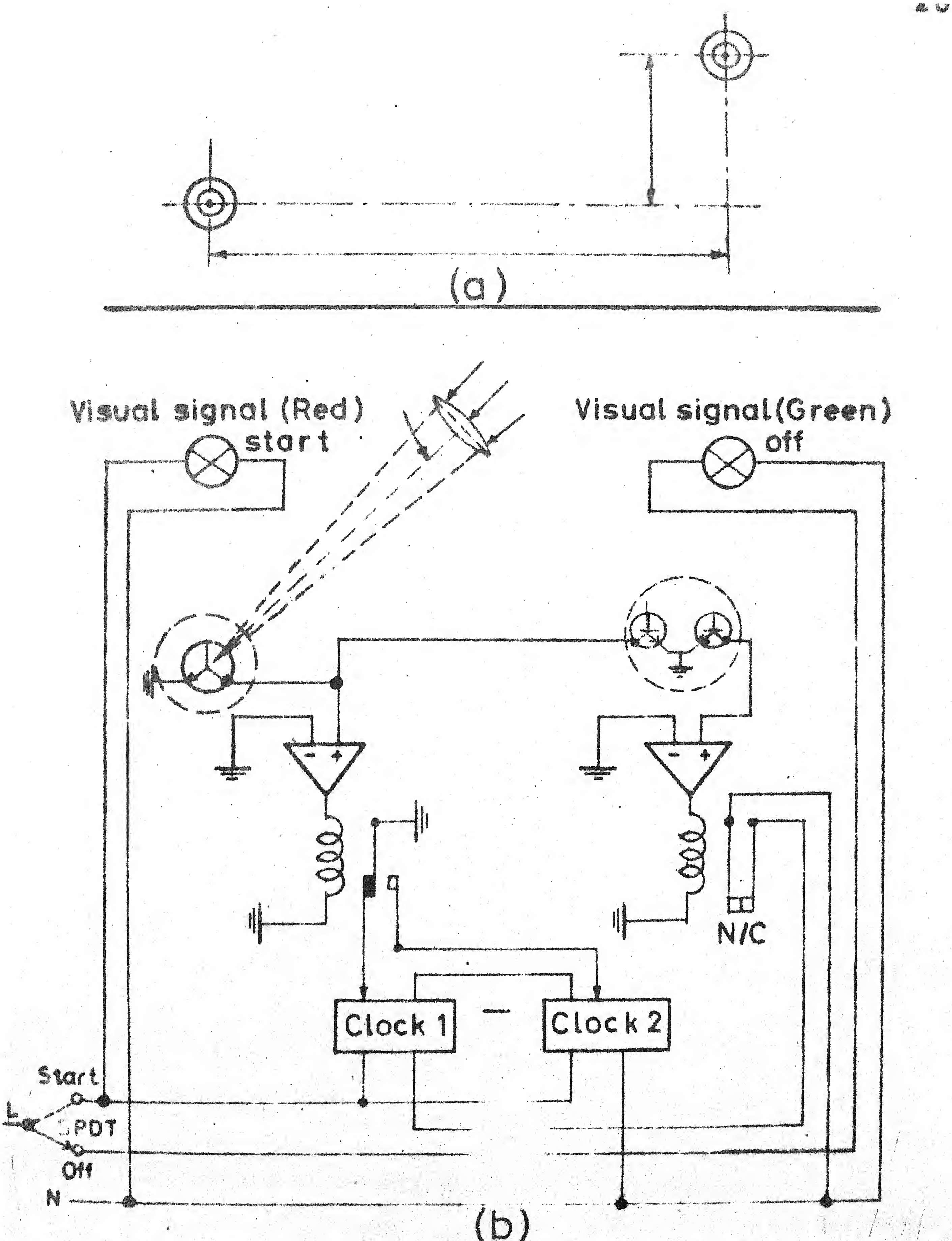


Fig. 7 (a) Relative Positions of the Targets
(b) Circuit Diagram showing the operations of the Timers and the Visual Signals

surface when the subject was in the seat was about 100^{o}. A foot rest was provided at a distance of about 18" below and 18", in front of the seat. A steering mechanism was fitted in front of the seat and its height above the seat inclination with the horizontal plane was adjusted so as to almost match with that in a typical Indian ambassador car. Fig. 2 shows the photograph of the seating arrangement and the steering mechanism attached to it.

2.3 THE TASK DESIGN:

A task to study the hand and foot coordination of a number of subjects was designed for the purpose. This was quite representative of the steering task in ordinary road vehicles. Two wires from steering wheel and two from the foot paddles went to a gyroscope fitted on the environmental chamber wall behind the seat of the subject. A small circular mirror was fitted onto the gyroscope and it could be rotated about horizontal and vertical axes on getting motion from the steering wheel and the foot paddles through the wires attached to it. A beam of light from a source attached to the ceiling of the chamber was thrown on the mirror. The reflection of the light beam was seen on a screen fitted on the front wall of the chamber. Thus it was possible to move the reflected light horizontally and vertically by actuating the steering wheel and the foot paddles. Two circular targets each fitted

with a photo transistor at its centre were specified on the screen at horizontal and vertical distances of $5'$ and $2'$ apart respectively. Two electric bulbs, one red and the other green, were fitted on the screen near the left and right side targets respectively. When the steering and the foot paddles were in their original positions, the reflection of the light beam fell on the photo transistor fitted to the left side target. This represented the condition that the subject was driving straight. Now the red light was switched on by an experiment controller sitting inside the chamber to indicate that some obstacle had come in subject's way. Then the subject, by actuating the steering wheel and foot paddles, was asked to remove the light from the left side target and reach the right side target. With the switching on of the red bulb one of the two timers started and it stopped as and when the light was removed from the left side target and thus gave the reaction time of the subject. With the removal of the light beam from the left side target the second timer started and it ultimately stopped when the subject brought the light beam on the right side target. This timer gave the task performance time. Thus the main task of each of the subjects was to remove the reflected light from the centre of left side target and bring it to the centre of right side target on getting signal from the experiment controller and to accomplish the same he had to properly actuate the steering

wheel and the foot paddles. After completion of the task the green bulb which was connected to the red bulb by means of a two-way switch was switched on and the subject was asked to take the light to its initial position. This completed one cycle of task performance and throughout the experiment the same cycle was repeated again and again. Fig. 7a and 7b show the relative positions of the targets and the circuit diagram for the timers and the bulbs.

CHAPTER III

DATA COLLECTION AND ANALYSIS

The main aim of human factors discipline is to apply the relevant informations about human characteristics and behaviour to the design of man-environment systems. The information input is made by way of various data collected through investigation and experience. The reliability of the result very much depends upon the method and accuracy with which data are collected. This chapter is devoted to the discussion of experimental design used and the experimental procedure of collecting data and their analysis.

3.1 EXPERIMENTAL DESIGN:

In the present study a 3x3x3x12 completely randomised full factorial design is used with three levels each of the vibration frequency, amplitude and temperature. Each of the subjects is tested under these experimental conditions for a duration of one hour. The following is a brief discussion of each of the factors investigated.

Frequency: The use of frequency as a factor is dictated by the sensitivity of human body to vibrations at certain frequencies peculiar to the mechanical properties of human body.

As the human performance is known to be significantly affected in low frequency range only, the levels chosen are 5, 10 and 15 Hz. These values cover the range of frequencies found in commonest transportation vehicles [13].

Amplitude: The levels of amplitude of vibrations encountered in ships on rough seas high speed air-craft flying at low altitudes and road vehicles are quite on large side. This is why low-frequency and high-amplitude vibrations have been of considerable interest to researcher working in this area. Keeping the machine constraint on amplitudes in view, the levels of amplitude chosen are 0.09 in., 0.12 in. and 0.15 in. DA.

Temperature: The levels of temperature used in the present study are 70°F, 85°F and 100°F. These values cover a fairly large range of temperatures, from mildly cold to fairly hot that generally exist, in Indian environmental conditions.

Exposure Time: The duration of vibration exposure has been kept as one hour in the present study. This is based on the subjective responses of the subjects under the given conditions. The following table gives the summary of factors for experimental design.

Table 1: Summary of Factors for Experimental Design.

Factor	Symbol	Level	Type Effect
Frequency	f	(i) 5 Hz (ii) 10 Hz (iii) 15 Hz	Fixed
Amplitude	A	(i) 0.09 in.DA (ii) 0.12 in.DA (iii) 0.15 in.DA	Fixed
Temperature	T	(i) $70^{o}F$ (ii) $85^{o}F$ (iii) $100^{o}F$	Fixed
Exposure Time Duration	t	One hour 12 levels each after 5 minutes duration	Fixed

3.2 COLLECTION OF DATA:

Subject: Six male subjects in the age group of 22 to 30 from among IIT Kanpur graduate students were selected as being physically qualified to participate in the experiment. None of the subjects was suffering from any physical disability. The experimental set up was shown and the function of each unit and the purpose of investigation was explained to all subjects. They were trained to perform the task for quite some time. All of the subjects showed their interest in the study.

Experimental Procedure:

A complete discription of each treatment cell is shown in Table 2. Each of the 6 subjects were tested in each of the 27 treatment cells. The duration of exposure was kept one hour in each case.

For randomization of the treatments, treatment cells were divided up into triads, having all three frequency levels, amplitude levels and temperature levels represented in each triad. These triads were assembled containing every possible order of all of the treatments and then they were arranged in sets so that all the 27 treatment conditions were represented in each set. Now all the 6 subjects were randomly assigned to these sets.

From medical standpoint subjects were tested only once in a day. In the beginning all the subjects were given learning trials for short durations under non-vibrating conditions. Afterwords, they were administered familiarisation ride for some time on the shake table. On the day of experiment, the subject was given all the relevant

Table 2: Description of Treatment Cells.

		$T_1 = 70^oF$			$T_2 = 85^oF$			$T_3 = 100^oF$		
		A_1	A_2	A_3	A_1	A_2	A_3	A_1	A_2	A_3
F_1	5 Hz	.09"	.12"	.15"	.09"	.12"	.15"	.09"	.12"	.15"
F_2	10 Hz	.09"	.12"	.15"	.09"	.12"	.15"	.09"	.12"	.15"
F_3	15 Hz	.09"	.12"	.15"	.09"	.12"	.15"	.09"	.12"	.15"

instructions before starting the same. The subject was asked to perform the specified task on getting a random signal from an experiment controller sitting in the chamber. In each case reaction time and the performance time were noted. The first few readings were discarded to reduce the learning effect. The reaction time and the task performance time were noted at an interval of five minutes-although the subject went on performing the task continuously for one hour duration. For the purpose of tabulation the mean of five readings obtained at a particular instant was taken as the reaction time and the performance time at that instant. Also the heart rates of the subjects were measured before and after the exposure of the different environments. The level of sound was also measured.

3.3 ANALYSIS OF DATA:

In any experiment of the aforesaid nature data are collected in order that on analysis, they may yield some valid inferences. Ours was a four-factor problem involving vibration frequency, amplitude, temperature and exposure time. For the purpose of analysis these factors have been treated as fixed factors and they have been considered at 3,3,3 and 12 levels respectively. The data as obtained in the lastsection were arranged in a 4-way cross classification which was further reduced to six two-way tables. Each of these tables was analysed using two-factor ANOVA programme. A

computer programme written in FORTRAN 10 was implemented on DEC 1090 system for performing the ANOVA. Also the Duncan's Multiple Range Test [28] was conducted to compare the individual levels of frequency. Finally a model to predict the performance time was developed through Linear Multiple Regression. Tables 3 to 8 show the ANOVA of performance time for different problems.

Table 3: ANOVA of Performance Time (Freq. and Temp.)

Source of Variation	Amount of Variation (SS)	Degrees of Freedom (df)	Mean Squares (MS)	F	Findings $\alpha = 0.05$
Between Treatments	2934.196	8	366.774		
Freq.	2889.732	2	1444.866	6.26	Significant
Temp.	10.77	2	5.385	0.02	Not significant
Interaction	33.693	4	8.423	0.04	Not significant
Error	8311.323	36	230.87		

Table 4: ANOVA of Performance Time (Ampl. and Temp.)

Source of Variation	Amount of Variation (SS)	Degrees of Freedom (df)	Mean Squares (MS)	F	Findings $\alpha = 0.05$
Between Treatments	254.734	8	31.84		
Ampl.	239.005	2	119.502	0.53	Not significant
Temp.	10.79	2	5.396	0.02	Not significant
Interaction	4.925	4	1.231	0.01	Not significant
Error	8052.067	36			
Total	8306.79	44			

Table 5: ANOVA of Performance Time (Freq. and Ampl.)

Source of Variation	Amount of Variation (SS)	Degrees of Freedom (df)	Mean Squares (MS)	F	Findings $\alpha = .05$
Between Treatments	3218.849	8	402.356		
Freq.	2914.919	2	1457.459	6.63	Significant
Ampl.	238.798	2	119.399	0.54	Not significant
Interaction	65.13	4	16.282	0.07	Not significant
Error	7918.95	36	219.97		
Total	11137.80	44			

Table 6: ANOVA of Performance Time (Exp. Time and Temp.)

Source of Variation	Amount of Variation (SS)	Degrees of Freedom (df)	Mean Squares (MS)	F	Findings $\alpha = .05$
Between Treatments	343.824	35	9.823		
Exp.Time	333.521	11	30.32	2.13	Significant
Temp.	3.592	2	1.796	0.13	Not significant
Interaction	6.711	22	0.305	0.02	Not significant
Error	2051.601	144	14.247		
Total	2395.426	179			

Table 7: ANOVA of Performance Time (Exp.Time and Freq.)

Source of Variation	Amount of Variation (SS)	Degrees of Freedom (df)	Mean Squares (MS)	F	Findings $\alpha = 0.05$
Between Treatments	1167.885	35	33.368		
Exp.Time	340.013	11	30.91	2.23	Significant
Freq.	724.292	2	362.146	26.18	Significant
Interaction	103.578	22	4.708	0.34	Not significant
Error	1971.708	144	13.831		
Total	3159.593	179			

Table 8: ANOVA of Performance Time (Exp.Time and Ampl.)

Source of Variation	Amount of Variation (SS)	Degrees of Freedom (df)	Mean Squares (MS)	F	Findings $\alpha = .05$
Between Treatments	199.591	35	5.702		
Exp. Time	164.353	11	14.941	0.76	Not significant
Ampl.	30.552	2	15.276	0.78	Not significant
Interaction	4.685	22	0.212	0.01	Not significant
Error	703.750	36	19.548		
Total	903.341	71			

Results of the Duncan's Multiple Range Test are summarised below:

	I_o	I_1	$SSR_{0.05}$
$\bar{F}_1 = 40.226$	9.716	19.628	19.488
$\bar{F}_2 = 49.942$		9.912	16.285
$\bar{F}_3 = 59.854$			

40.226	49.942	59.854
$\bar{F}_1$	$\bar{F}_2$	$\bar{F}_3$

Here I_o and I_1 indicate zero and one intervening means respectively and $SSR_{0.05}$ represents the shortest significant range for a given significance level of 0.05. The values of I_o and I_1 have been taken from Table I (Appendix B) [28]. The interpretation of the results thus obtained has been given in the next chapter.

CHAPTER IV

INTERPRETATION OF RESULTS

In the previous chapter the experimental design to obtain appropriate data has been discussed. Later on, these data are analysed statistically to draw inferences with respect to the experiments conducted. The results obtained in Chapter III are interpreted in the present Chapter. The interpretation includes the discussions on the nature of graphs and the statistical inferences drawn from the analysis.

4.1 DISCUSSIONS ON GRAPHS:

Figure 8 to 16 show the plots of mean Performance Time vs. Exposure Time at different levels of frequency and temperature. Performance time is found to be increasing with the increase in vibration exposure time at all levels of frequency and temperature. However, it remains almost constant at the frequency level of 5 Hz. Performance time increases considerably after 15-20 minutes of vibration exposure. Upto 15-20 minutes of vibration exposure there is not much difference in the performance times at different levels of frequency. Temperature does not affect the performance time to the extent as frequency does. However, the performance time certainly increases with the environmental temperature, the difference being practically nil between the levels of

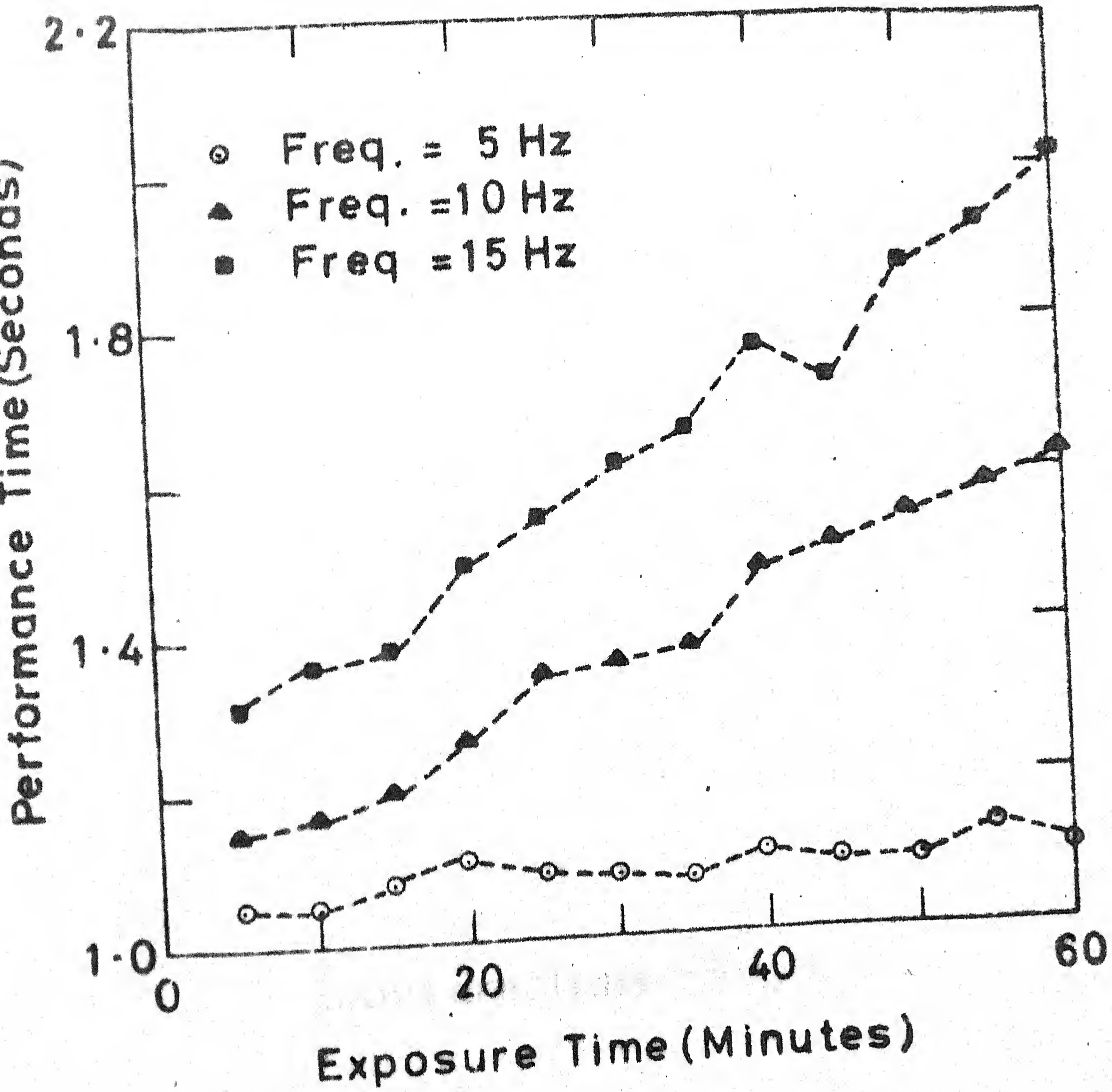


Fig. 8 Performance Time vs Exposure Time at Temp. = 70° F

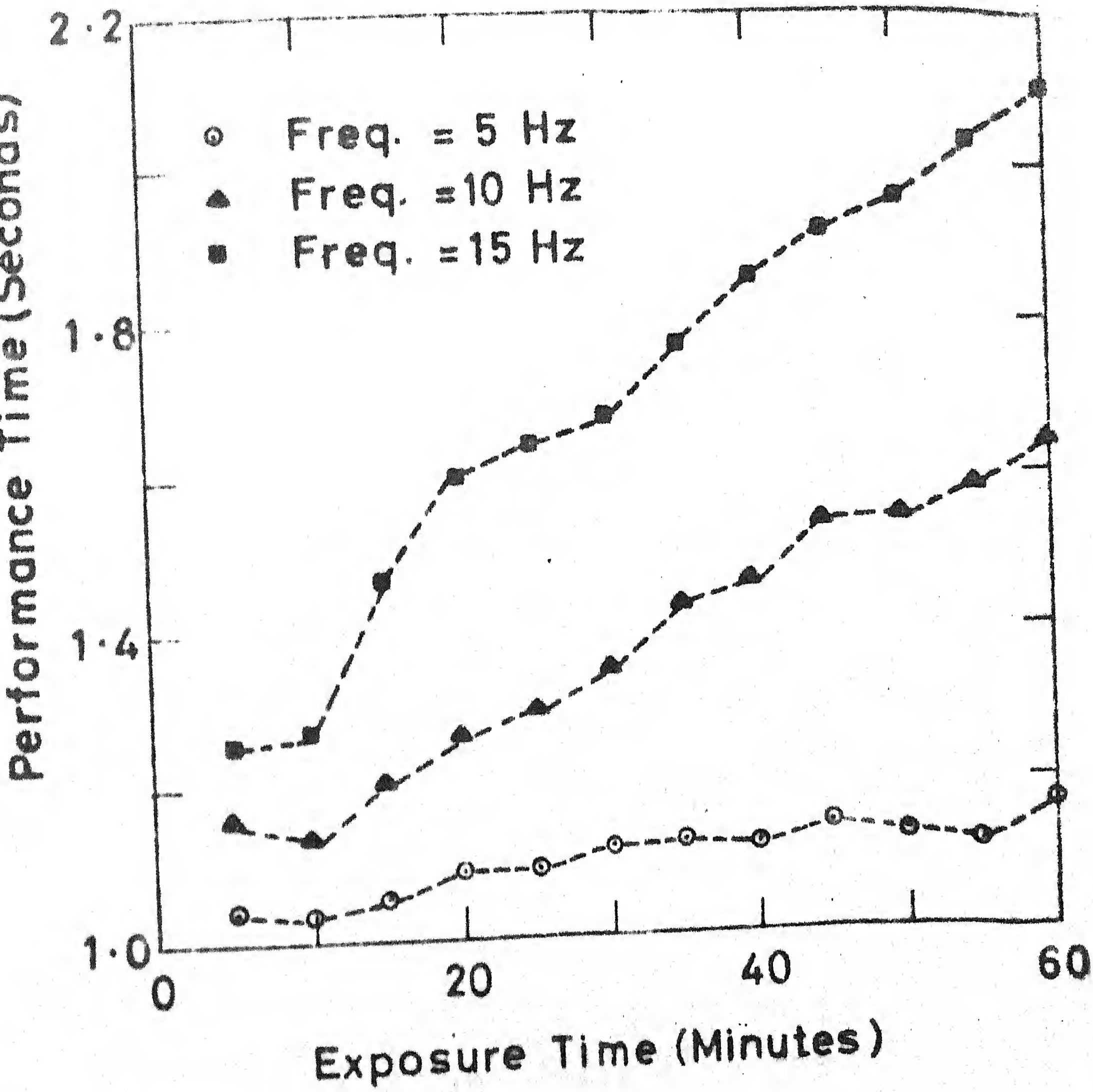


Fig. 9 Performance Time vs. Exposure Time at Temp. = 85° F

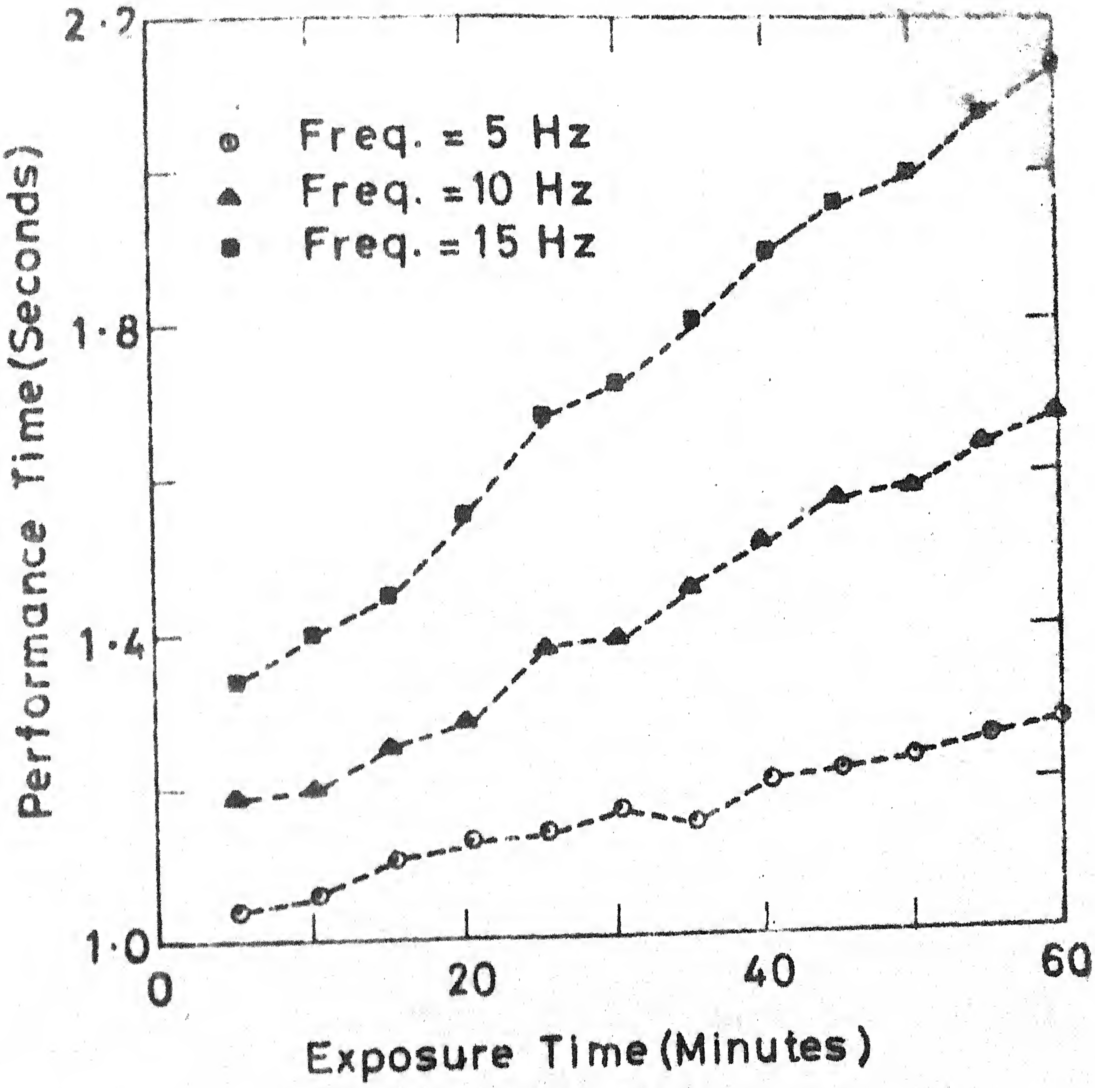


Fig. 10 Performance Time vs Exposure Time at Temp. = 100° F

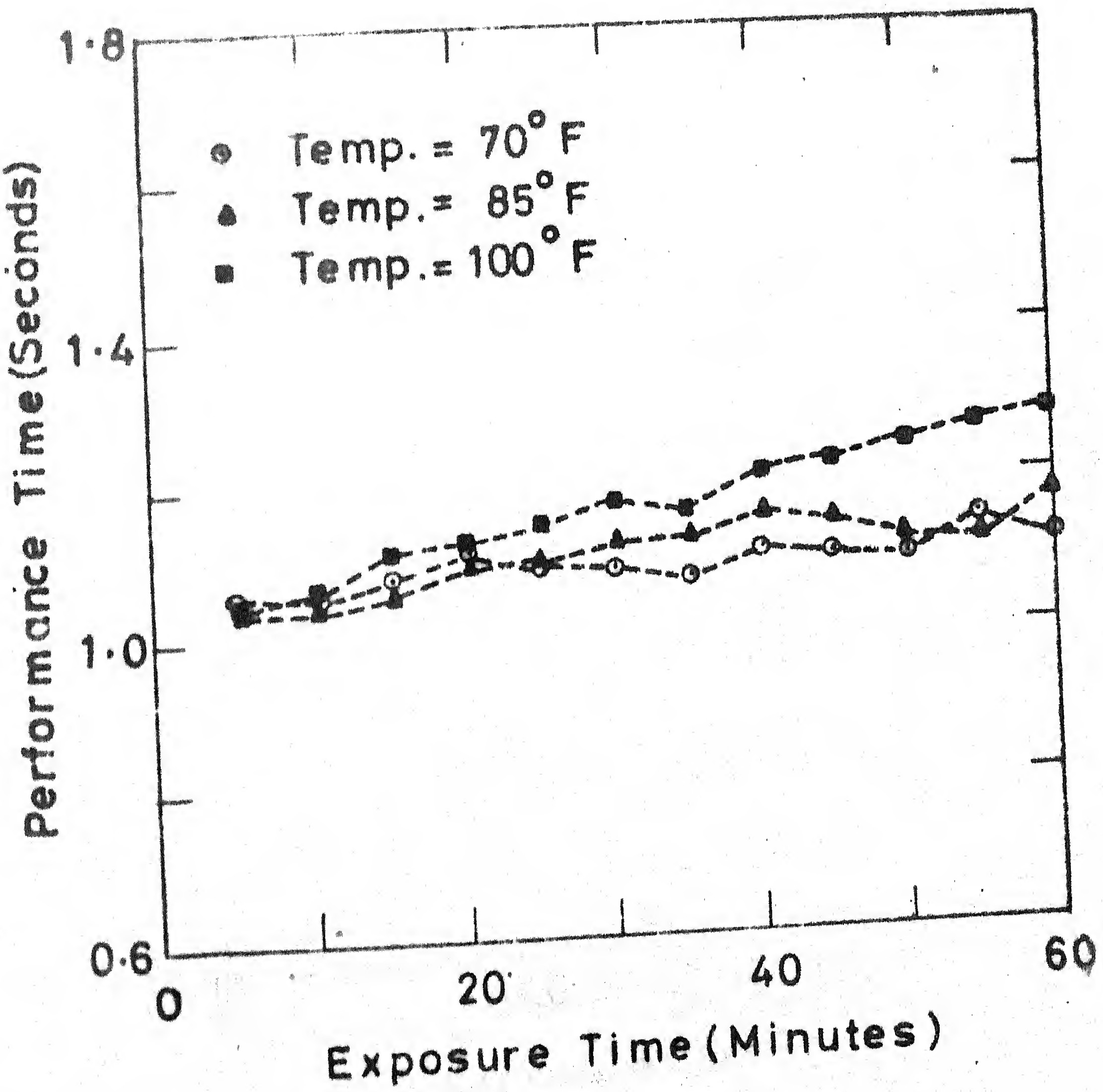


Fig.11 Performance Time vs Exposure Time at Freq. = 5 Hz

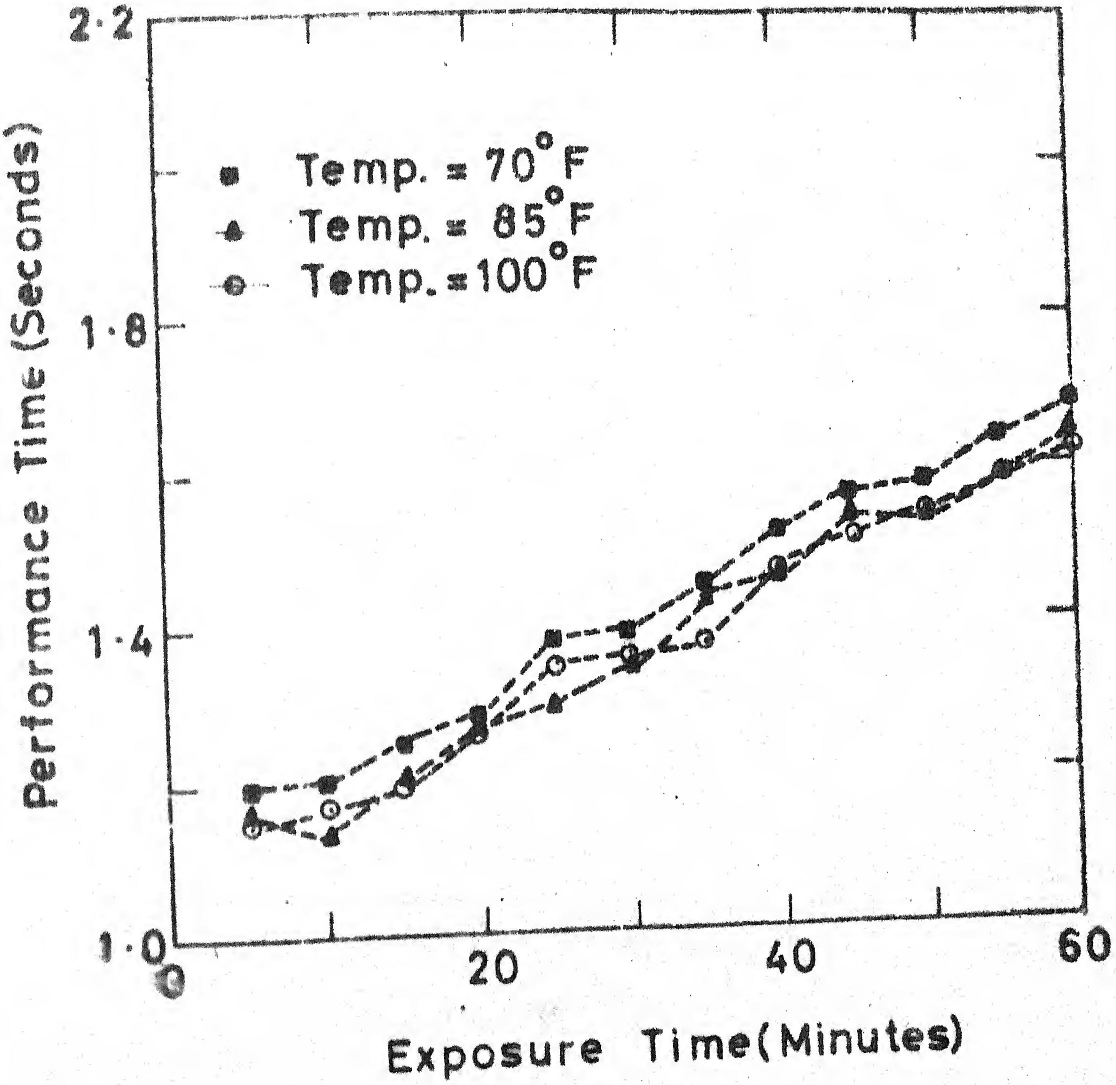


Fig. 12 Performance Time vs Exposure Time at Freq. = 10 Hz

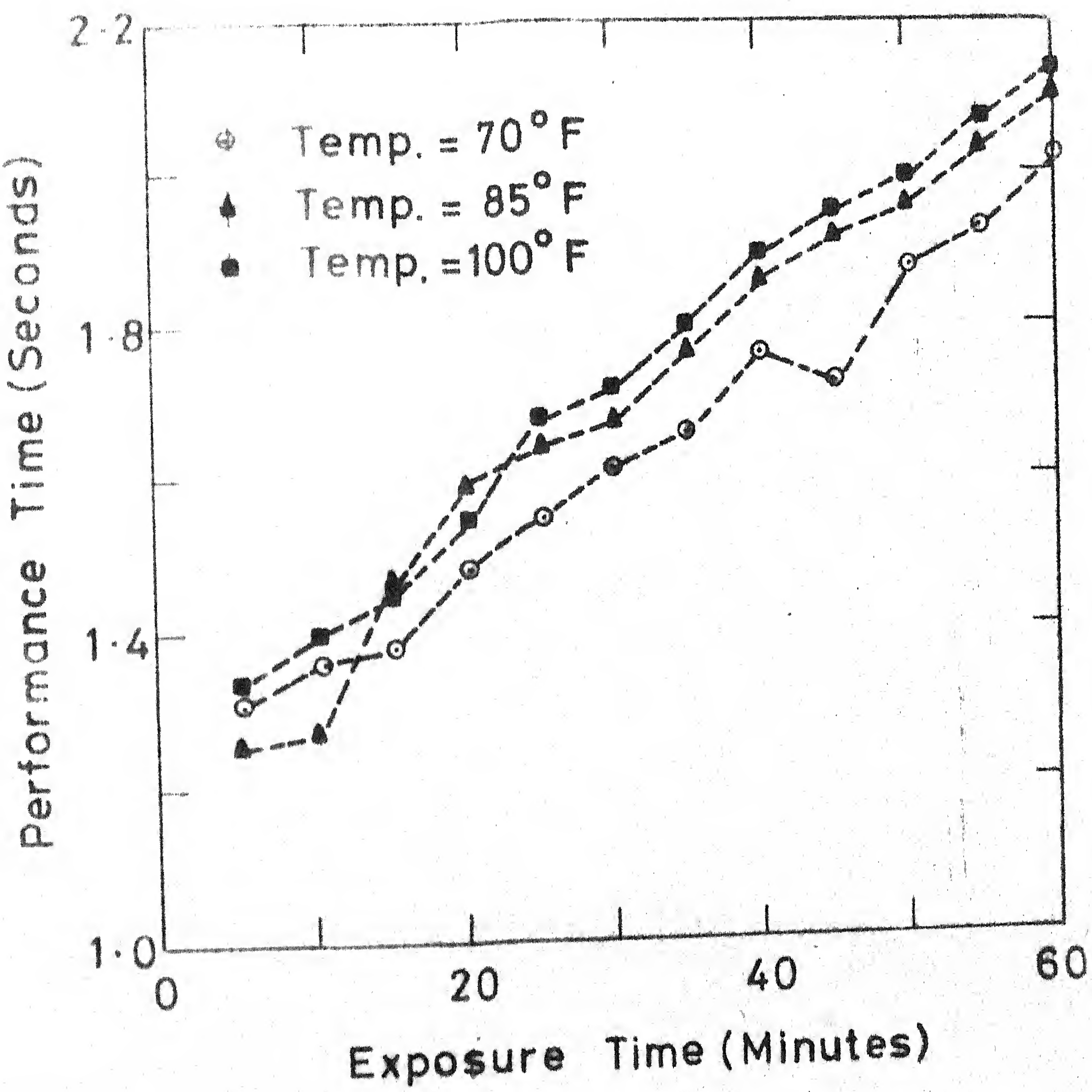


Fig.13 Performance Time vs Exposure Time at Freq. = 15 Hz

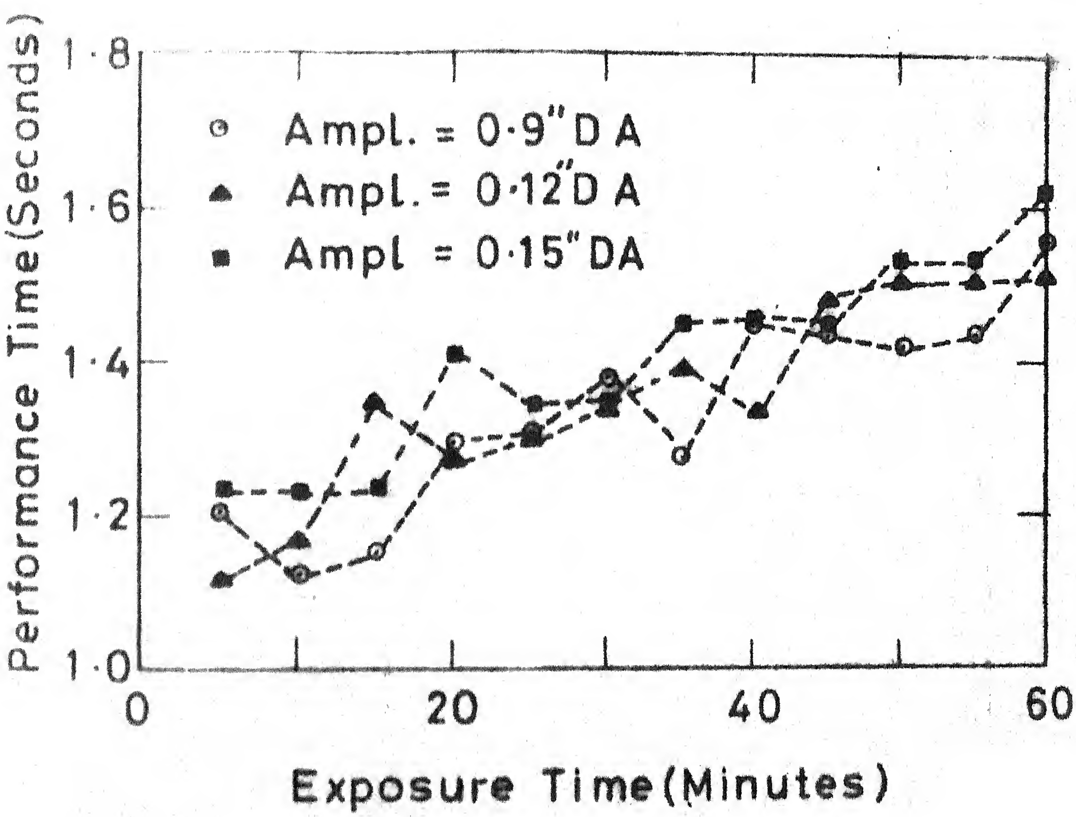


Fig.14 Performance Time vs Exposure Time at Freq. =5Hz

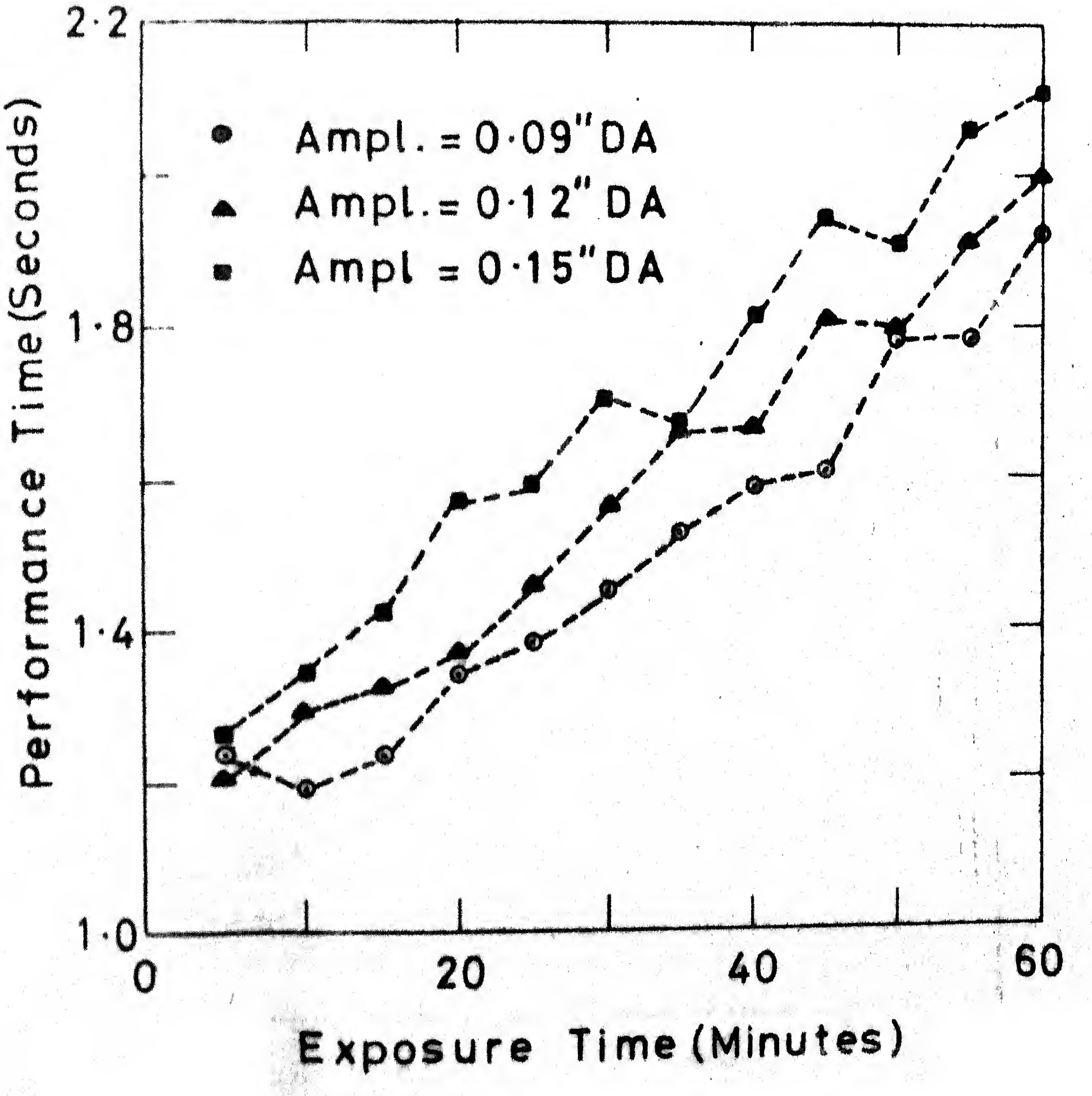
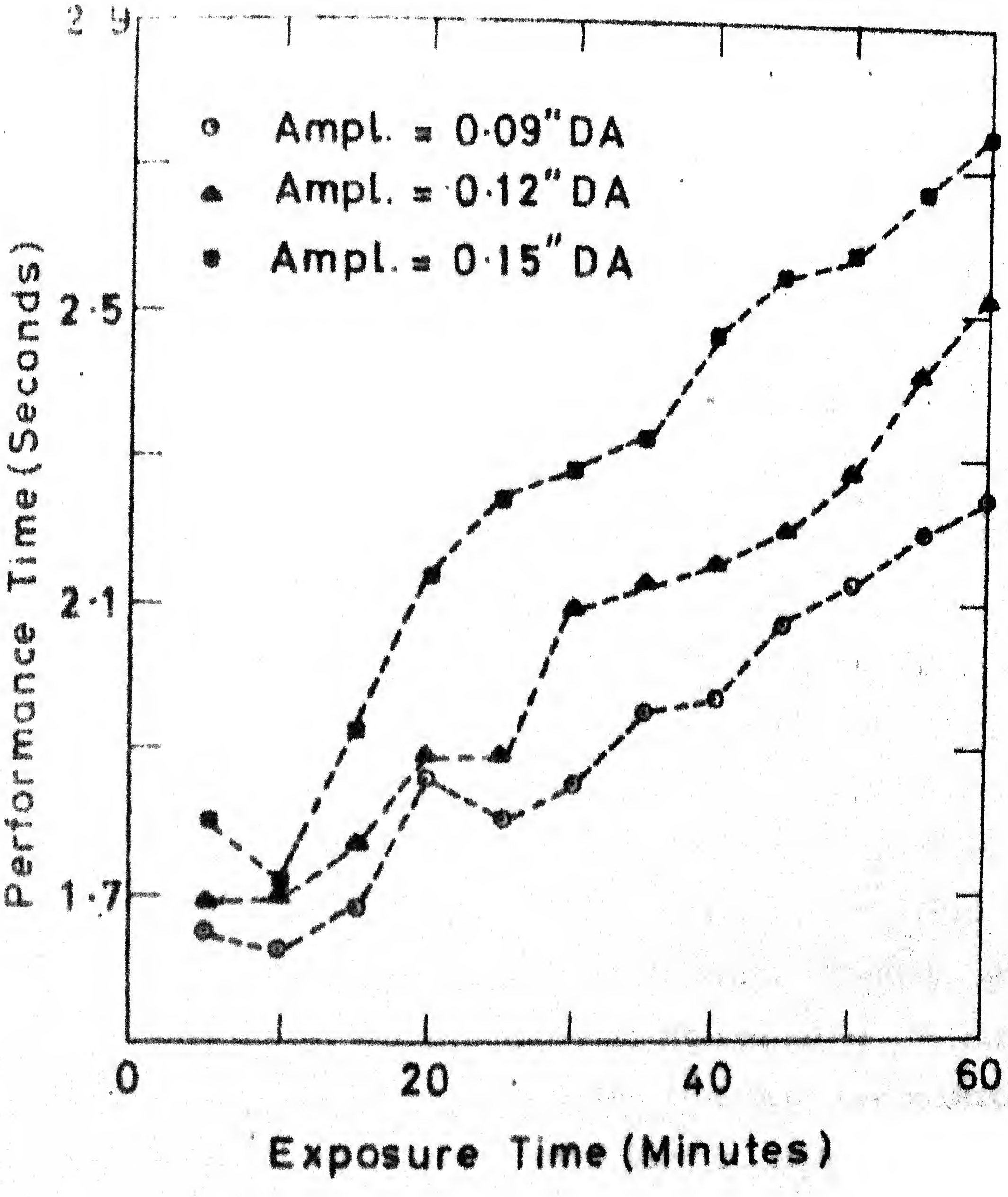


Fig. 15 Performance Time vs Exposure Time at Freq. =10 Hz



16 Performance Time vs Exposure Time at Freq.=15 Hz

$70^{\circ}F$ and $85^{\circ}F$. Like temperature, amplitude also does not have the same effect as frequency but it causes increase in the performance time, the increment being maximum at 0.15" DA.

The experimental data themselves show that reaction time and heart rates are quite resistant to the environmental conditions under study.

4.2 STATISTICAL INFERENCE:

The ANOVA tables given in Chapter III indicate that no two factor interaction is significant. Since the replications in each of the treatment cells are sufficiently large in humber to randomise the error, it can be safely concluded that three and higher order interactions will be insignificant.

Frequency is found to be highly significant at 0.05 and 0.01 levels of significance. The Duncan's Multiple Range Test conducted to analyse the differences, if any, among the treatment means at different levels of frequency shows that the treatment mean at 5 Hz significantly differs from that at 15 Hz at 5 percent level of significance. However, the differences between the means at 5 Hz and 10 Hz and also 10 Hz and 15 Hz are not significant. The treatment means which are not significantly different from each other have been underlined simultaneously. The reason for these means not being significantly different, even though they very much differ apparently, may be that the standard error involved is quite

large and hence even a relatively large mean difference failed to exceed the SSR value, necessary for significance. The vibration exposure time is also found to be significant at the significance level of 0.05. The amplitude and temperature are not found to be significant at this level. However, the performance time means differ noticeably from one another at various levels of amplitude as well as temperature.

Various models for predicting performance time (T) for known values significant factors, viz., frequency (f) and vibration exposure time (t) have been tested and the following model has been found to adequately fit as indicated by the F value.

$$T = 5.5302 + 0.0643\,t + 0.4946\,f$$

The calculated value of F = 1.999. The F value as obtained from tables corresponding to 5 percent significance level = 5.3177 and this is greater than the calculated "F" value. Hence the model needs no further modification.

CHAPTER V

CONCLUSIONS AND SCOPE FOR FURTHER WORK

5.1 CONCLUSIONS:

Based on the statistical inferences drawn in the last chapter, the following general conclusions can be made within the limits of environmental conditions studied.

1. The task performance time increases significantly with the increase in vibration frequency, the increment being minimum at 5 Hz. This does not conform to the findings of Magid et.al.[15] and Shoenberger and Harris [22]. The probable reason may be that the acceleration at 5 Hz could not be increased beyond $\pm$ 0.199 g_z due to the amplitude constraint of the machine.

2. The vibration exposure time significantly affects the performance time, the rate of increment being extremely high after 15-20 minutes of exposure.

3. Temperature does not significantly affect the performance time. However, the effect is quite noticeable at 100°F. The performance time is minimum around 70°F.

4. The amplitude of vibration has no significant effect on performance time. However, its effect at relatively higher

level such as 0.15" DA is quite considerable. This does not seem to be intuitively sound. The machine puts a constraint on the upper limit of vibration amplitude equal to 0.15 in. DA. Had higher levels of amplitude been possible to attain, it could have some significant effect on the performance time.

5. The reaction time and heart rates of the subjects are quite resistant to the environmental conditions.

6. As a part of conclusion the following model is proposed for the prediction of performance time (sec.) when f (Hz) and t (min.) are given:

$$T = 5.5302 + 0.0643\ t + 0.4946\ f$$

However, verification is needed before the model may be put to use.

5.2 SUGGESTIONS FOR FURTHER WORK:

In the present work conclusions have been drawn on the basis of the performance of a single task. To make these conclusions move sound several tasks similar to those encountered in real life situations may be designed and performed. Similarly the informational load on the subjects has been kept constant. The informational load may also be varied and made a factor of interest. The complexity of task may be a factor which one may be interested in. The variation in task complexity may be accomplished by slight modification in the design of the task. Moreover, several other factors such as noise,

illumination may be considered in conjunction with the vibration and their combined effects may be studied. In vibration itself several generalisations are possible. One of these may be to study the effects of multi-directional vibration on human performance.

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